THE GREEN TURTLE, *CHELONIA MYDAS*, IN QUEENSLAND. POPULATION STRUCTURE IN A WARM TEMPERATE FEEDING AREA.

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Chelonia mydas resident in the Moreton Banks within eastern Moreton Bay, southeastern Queensland, encompass all size classes from immature turtles with a curved carapace length of 39cm to mature adults of both sexes. The population sex ratio is strongly biased to females (66%) and to immature size classes (89% of females, 96% of males). Sexual maturity does not usually occur at the minimum breeding size for the species. Tag recoveries indicate that most of the adult females migrate to breed at the southern Great Barrier Reef rookeries. Individual females do not breed annually. Approximately 10% of the population shows signs of anthropogenic impacts which range from fibropapillomas to propeller damage. Regression equations for converting between the various measurement methodologies for marine turtles are presented for this population. ☐*Chelonia mydas, Moreton Bay, sex ratio, sexual maturity, migration.*

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Feeding area studies of *Chelonia mydas* in Queensland began in 1974 at Heron Island Reef (Limpus & Walter, 1980; Limpus & Reed, 1985a; Limpus, 1992a). In 1986, the study expanded to include other study sites in eastern Queensland to investigate the regional population dynamics of the species. The most recent and most southerly study site incorporated into this regional study is in Moreton Bay in southeastern Queensland. This study provides the first systematic assessment of the demography of *C. mydas* in a non-tropical Australian feeding area. The initial phase of this study has been to establish a tagged population of measured turtles for continuing long-term studies. The first results from the Moreton Bay study site are reported here.

METHODS

Turtles were captured using the turtle rodeo capture method (Limpus and Reed, 1985a) in the intertidal flats and the adjacent margins of the Moreton Banks between July 1990 to June 1992. Each turtle was tagged with one or more tags applied in the front flipper axillary tagging positions (Limpus, 1992a). The tags were either large size, 125 CPT titanium turtle tags (Stockbrands Pty. Ltd., Perth, Western Australia. Limpus, 1992a) or inconel 625 turtle tags (National band and Tag Co. New Port, Kentucky; Balazs, 1983).

Curved carapace measurements were taken using a flexible fibreglass tape measure (± 0.5cm) laid over the curve of the carapace. These measurements are the standard measurements used for *C. mydas* in eastern Australia by Bustard (1972) and Limpus et al. (1984). The calibration of fibreglass tape measures was checked regularly against steel rules. A tape measure was rejected for use when length changes exceeded ± 0.22cm at one metre. Any large barnacles on the carapace likely to interfere with a measurement were removed.

Curved carapace length (CCL) was measured along the midline from the junction of the skin and carapace above the neck to the posterior margin of the carapace at the midline junction of the supracaudal scutes. Curved carapace width (CCW) was measured perpendicularly to the midline axis of the carapace between the outer extremities of the marginal scutes. This measurement was repeated at several positions to obtain the greatest value. Straight carapace length (SCL) and straight carapace width (SCW) were taken between the same points as the corresponding curved measurements (CCL, CCW) but using a large pair of wooden callipers (Hughes, 1974; Limpus et al., 1983). The width between the tips of the callipers was measured with a steel tape measure (± 0.1cm). Carr's straight carapace length (CSCL) was measured as a straight line

TABLE 1. Frequency distribution of all recoveries of tagged adult female *Chelonia mydas* from Moreton Bay which had been previously tagged while nesting at rookeries throughout the Great Barrier Reef (Limpus et al., 1992; and unpublished records of the Queensland Turtle Research Project). These data include the three recaptures (*) of migrant females from the Moreton Banks of the present study.

Rookery	Breeding Season						
	77/78	81/82	84/85	87/88	88/89	89/90	90/91
Southern Great Barrier Reef rookery region							
LM	1				1*	1	
HI			2			2*	
WI		1	2	1			
NW			1	1*		1	1
Northern Great Barrier Reef rookery region							
RI			1				
Total (n=16)	1	1	6	2	1	4	1

LM = Lady Musgrave Is. (23°54'S, 152°23'E); HI = Heron Is. (23°26'S, 151°55'E); WI = Wreck Is. (23°20'S, 151°57'E); NW = North West Is. (23°18'S, 151°42'E); RI = Raine Is. (11°36'S, 144°01'E).

length from the most anterior to the most posterior projections of the carapace (Carr & Ogren, 1960). This is not a midline measurement. Head measurements were taken using stainless steel vernier slide callipers (± 0.01cm). Head length (HL) was measured from the anterior tip of the maxillary sheath (upper beak) to the posterior margin of the supraoccipital process, keeping the arm of the callipers parallel to the dorsal surface of the skull. Head width (HW) was measured as the maximum width across the skull measured at the quadrate bone. Plastron length (PL) was measured using a flexible tape measure (± 0.5cm) along the midline from the anterior junction of the skin and plastron scutes to the posterior margin of the cartilaginous/bony plate. Tails were measured (±0.5cm) with either a steel or a fibreglass tape measure from the posterior edge of the midline junction of the supracaudal scutes to the tip of the extended straightened tail (TLC). A negative sign for this measurement indicates a distance short of the carapace margin. Turtles were weighed using 10, 100 or 200kg Salter spring balances (± 0.1, ± 0.5, ± 1.0kg respectively).

All turtles were measured for CCL except those with damage to the posterior carapace. An approximately random series of turtles were weighed and TLC measured. A group of immature turtles (31 females and 25 males) was selected from the turtles captured on 25 May and 21 September 1991 so that there were approximately five turtles of each sex represented in each 10cm increment of CCL in the range of 40-90cm and all measurements were taken on these turtles. Each turtle within this two year study has been analysed for only one set of measurements, usually those taken at the time of first capture. The number of turtle barnacles, *Chelonibia testudinaria*, with diameter >1cm on the carapace were counted. Where turtles were recaptured at greater than a one year interval, a second count of these barnacles for the turtle was included.

The gonads and associated reproductive ducts were examined using laparoscopy to assess sex, maturity and reproductive status of the turtle (Limpus & Reed, 1985a). The developmental features of the reproductive organs of marine turtles that can be used for assessment of sex, maturity and breeding status have been described : *C. mydas* (Limpus & Reed, 1985a,b), *Caretta caretta* (Limpus, 1985) and *Eretmochelys imbricata* (Limpus, 1992b). These developmental features were applied in assessment of sex and maturity. The year of breeding was determined as follows: a female was scored as breeding in the current breeding season if she was observed on a nesting beach, or if she was in advanced vitellogenesis in the months preceding a breeding season; she was scored as having bred in the previous breeding season if she had healing corpora lutea (= corpora albicantia) >3mm in diameter during the months following a breeding season; she was scored as having bred in the penultimate breeding season if she had corpora albicantia ~3mm in diameter. Not all turtles were sexed via laparoscopy. For those turtles not sexed via laparoscopy: when TLC >30cm, the turtle was arbitrarily rated as adult male; when CCL <90cm and the tail was not differentiated, the maturity status was rated as immature on the basis that the smallest recorded breeding adult female at the southern Great Barrier Reef (GBR) rookeries had CCL = 90cm (Limpus et al., 1984).

Data were obtained from the unpublished records of the Queensland Turtle Research Project for turtles recaptured in this study which had been tagged at other locations. These recaptures occurred for turtles from three study types.

1. *Feeding area studies.* In a continuing series of studies since 1974, many thousands of *C. mydas* have been captured, tagged and released

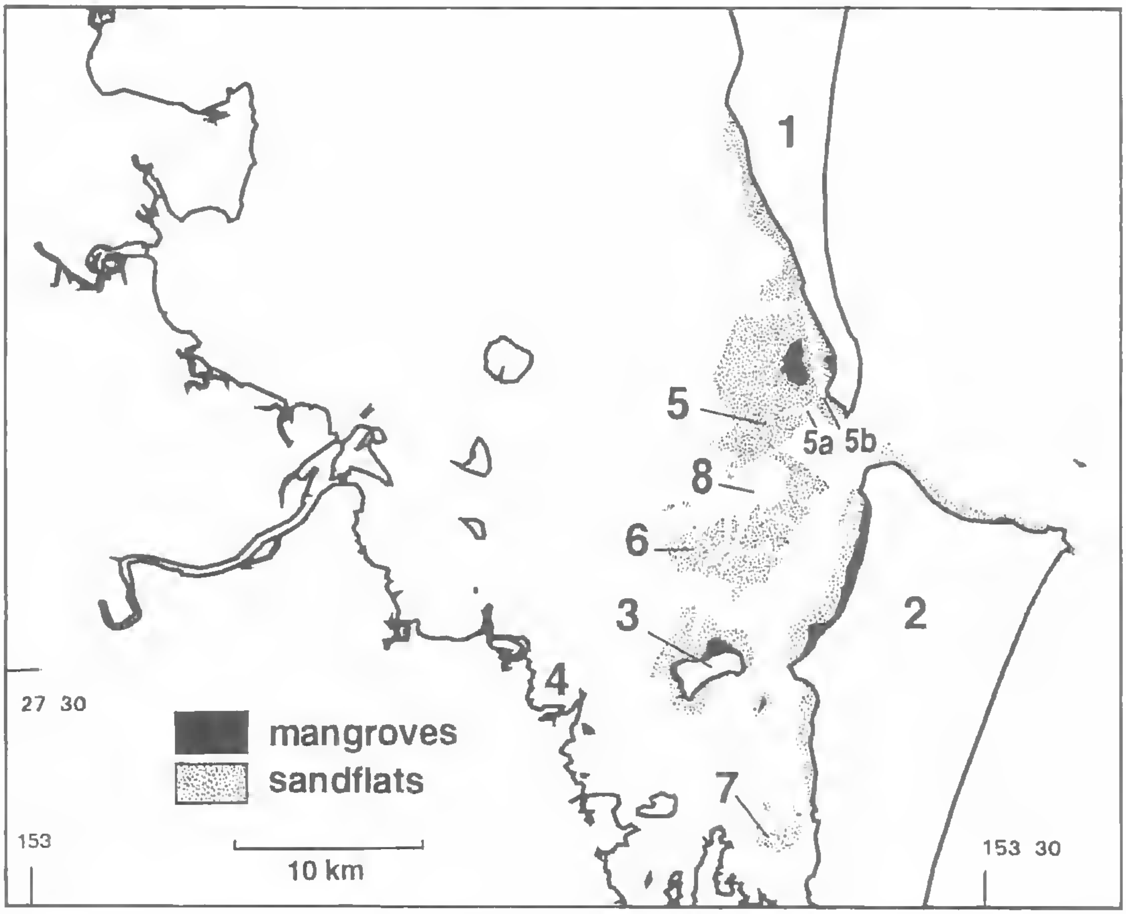

FIG. 1. Moreton Bay and the turtle research study sites, see text for details. 1, Moreton Island; 2, North Stradbroke Island; 3, Peel Island; 4, Raby Bay; 5, Moreton Banks; 5a, Browns Gutter, 5b; Days Gutter; 6, Maroom Banks; 7, Pelican Banks; 8, Rous Channel.

at Heron Reef and other reefs of the Capricorn-Bunker Groups, Shoalwater Bay, Repulse Bay, Green Island Reef and Clack Reef.

2. *Nesting studies.* Since 1971, tens of thousands of nesting female *C. mydas* have been tagged on nesting beaches in eastern Australia.

3. *Hatchling marking studies.* During the period January 1976 - March 1983, 108940 hatchling *C. mydas* were marked by mutilation tagging at Mon Repos and Heron Island (Limpus, 1985). These latter turtles can be identified to year and rookery of birth by the distinctive pattern of damage to a pair of marginal scutes (one scute on either side of the posterior carapace with symmetrically placed damage within each scute; Limpus, 1985). An arbitrary birth date of 1 February was assigned to these marked hatchlings within each breeding season.

Rainfall and air temperature data were obtained from the Bureau of Meteorology weather station at the Brisbane airport (27°26'S, 153°06'E). Surface water temperature data from the vicinity of the Moreton Banks during June 1988 to January 1990 was supplied by Dr. A. Preen. Water depths were obtained from local marine charts (Anon, 1987).

STUDY SITE

Moreton Bay (27°30'S, 153°18'E) is a large, wedge-shaped, semi-enclosed bay in south eastern Queensland adjacent to Brisbane (Fig. 1). It is approximately 100km long with a maximum width of 30km at its northern limit. It extends from the mouth of the Nerang River at 27°54'S in the south to the opening between Bribie Island and Moreton Island at 27.03°S in the north. Six

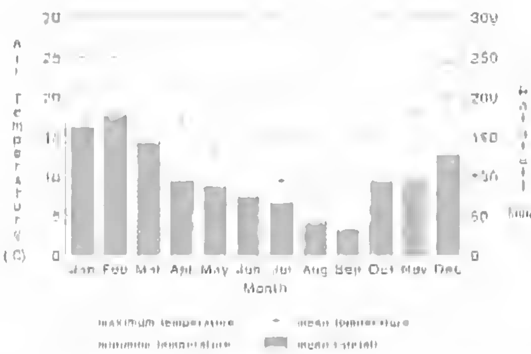

FIG. 2. The mean monthly air temperature and rainfall recorded at the Brisbane Airport for the years 1949 - 1992. Data obtained from the Bureau of Meteorology.

FIG. 3. Surface water temperatures recorded on the Moreton Banks. Data supplied by Dr. A. Preen

rivers discharge into Moreton Bay: Caboolture, Pine, Brisbane, Logan, Coomera, and Nerang Rivers. The southern, narrow, part of Moreton Bay consists of many small islands and narrow channels less than 6m deep (Young & Kirkman, 1975) while the northern portion is relatively open and reaches a maximum depth of 60m (Milford & Church, 1976). The eastern side of Moreton Bay is dominated by a large fan-shaped delta situated between Peel, Moreton and North Stradbroke Islands which is formed by the tidal movement of oceanic waters into Moreton Bay via the Rous Channel. The Moreton Banks form the northern portion of this fan-shaped delta. The sediments of the Moreton Banks are mostly quartz sand in contrast to the southern and western regions of Moreton Bay which are mud (Maxwell, 1970). The open areas of Moreton Bay have salinities close to full-strength seawater (34-35‰), while salinity decreases along the western side of Moreton Bay adjacent to the mainland coast where it approaches 33‰, or lower during floods (Milford & Church, 1976).

Mean air temperatures in Moreton Bay can vary between a maximum of 24.3°C in January to a minimum of 15.9°C in July (Newell, 1971). The range of the air temperature over the bay is narrower than the air temperature range over the adjacent mainland (Fig. 2). The mean monthly surface water temperatures follow approximately the fluctuations of the ambient air temperatures but are generally slightly higher. Mean monthly surface water temperatures in the vicinity of the Moreton Banks range approximately 16-28°C with usually <2°C variation between minimum and maximum temperature within a month (Fig. 3). The Moreton Bay area has a summer wet season during December to March and minimum monthly rainfall during August and September (Fig. 2).

TABLE 2. Immature *Chelonia mydas* captured on the Moreton Banks that had been marked by mutilation tagging when they were hatchlings at the Heron Island Rookery. See Fig. 4 for the marking pattern by which these turtles were identified to the year and rookery of birth after Limpus (1985)

Tag	Sex	Date	CCL(cm)	Age(yr)
T51184	Female	13 Oct 90	54.4	8.75
T47413	Male	10 May 92	68.0	11.25

This part of the Queensland coast is characterised by two tidal cycles per day with a tidal range of ~2.5m at highest spring tides to ~0.9m at neap tides (Anon, 1990). The Moreton Banks are covered in most areas by 2-6m of water at high tide and varying proportions of the banks are exposed at each low tide. The depth of these banks drops sharply to 10m along the southern edge which is delimited by the Rous Channel and to 15m along the western edge. The Moreton Banks cover an area of approximately 6290ha, with some 2513ha of seagrass meadow and another 3777ha of sparse or patchy seagrass (Hyland et al., 1989). The dominant vegetation of the Moreton Banks included: seagrasses (*Halophila ovalis, H. spinulosa, Halodule uninervis, Zostera capricorni, Syringodium isoetifolium*; Hyland et al., 1989), macroalgae (*Sargassum sp., Hypnea cervicornis, Gracilaria edulis, Hydroclathrus clathratus, Codium fragile*) and the grey mangrove (*Avicennia marina*; Dowling, 1986). The latter fringed the eastern margin of these banks and the adjacent small un-named island (27°20'S, 153°24'E).

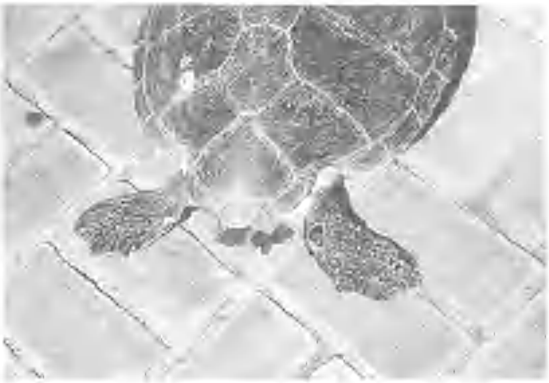

FIG. 4. Immature *Chelonia mydas* (tag number T51184) originally marked by mutilation tagging as a hatchling at Heron Island in February 1982. See Table 2 for details.

To identify capture sites within the Moreton Banks, the banks were divided into sectors which were defined by the boundaries of the low tide drainage areas (Fig. 1).

RESULTS

In the course of establishing tagged study populations, an attempt has been made to capture all turtles seen in shallow water habitats examined in Moreton Bay. Total captures (including recaptures) during this initial two years of study were: 1068 captures of 826 *C. mydas*, 447 captures of 320 *Caretta caretta* and 4 captures of 4 *Eretmochelys imbricata*. This report summarises the data recorded from the *C. mydas*.

A total of 1025 captures of 784 individual *C. mydas* were recorded on the Moreton Banks during this two year study. Numerous turtles were seen and captured on all occasions that the Moreton Banks were visited. No comparable concentration of *C. mydas* has yet been identified in other areas of Moreton Bay during our boat based transects or from discussions with local fishermen. During the last 18 months of the study an additional 42 *C. mydas* were captured elsewhere in Moreton Bay: 10 on the Maroom Banks, immediately south of the Rous Channel; 23 on the northern seagrass flats of Peel Island; 9 on the Pelican Banks. Of the 826 *C. mydas* examined in this study, only 6 were recaptures of turtles that had been tagged in studies elsewhere: 1 from other feeding area studies, 3 from nesting studies, 2 from hatchling marking studies. The ex-feeding area recapture (tag number T36994) was of an immature female that had been tagged while feeding at Heron Island Reef on 31 March 1990 (CCL = 77cm). It was recaptured 490km to the south at the Moreton Banks on 7 September 1991 (CCL = 78.5cm), with 525d between captures. The three adult females from nesting studies that were recaptured on the Moreton Banks originated from tagging studies in the southern Great Barrier Reef (Lady Musgrave Island, Heron Island and North West Island - tag numbers: X14662, T43877, T35025 respectively; Table 1). The two immature *C. mydas* that were consistent with having been marked by mutilation tagging when they were hatchlings had been marked at the Heron Island rookery (Table 2; Fig. 4). These latter turtles have recruited to live at a feeding area that is approximately 490km from their natal rookery.

FIG. 5. Portion of a days catch of *Chelonia mydas* from the Moreton Banks onboard the Research Vessel 'Sea World II'.

Because most of the Moreton Bay turtles captured at sites away from the Moreton Banks were not sexed, and given their small sample sizes, only the turtles captured on the Moreton Banks will be analysed for population structure. A typical catch of turtles within this study site is illustrated in Fig. 5. The size class distribution and sex of the 784 *C. mydas* captured on the Moreton Banks is summarised in Fig. 6A. They included turtles over a wide range of sizes from small immature turtles with CCL = 38.8cm up to adults with CCL = 119.1cm. There were no turtles captured in the size range between that of hatchlings (approximate CCL = 5cm; Limpus et al., 1984) and small immatures with CCL = 38cm. The most frequently captured turtles were small immatures in the CCL range of 40-65cm. The population structure by sex, size and maturity is summarised in Fig. 6B,C and Table 3. Of the 393 females examined for sex and maturity, there were 10.9%

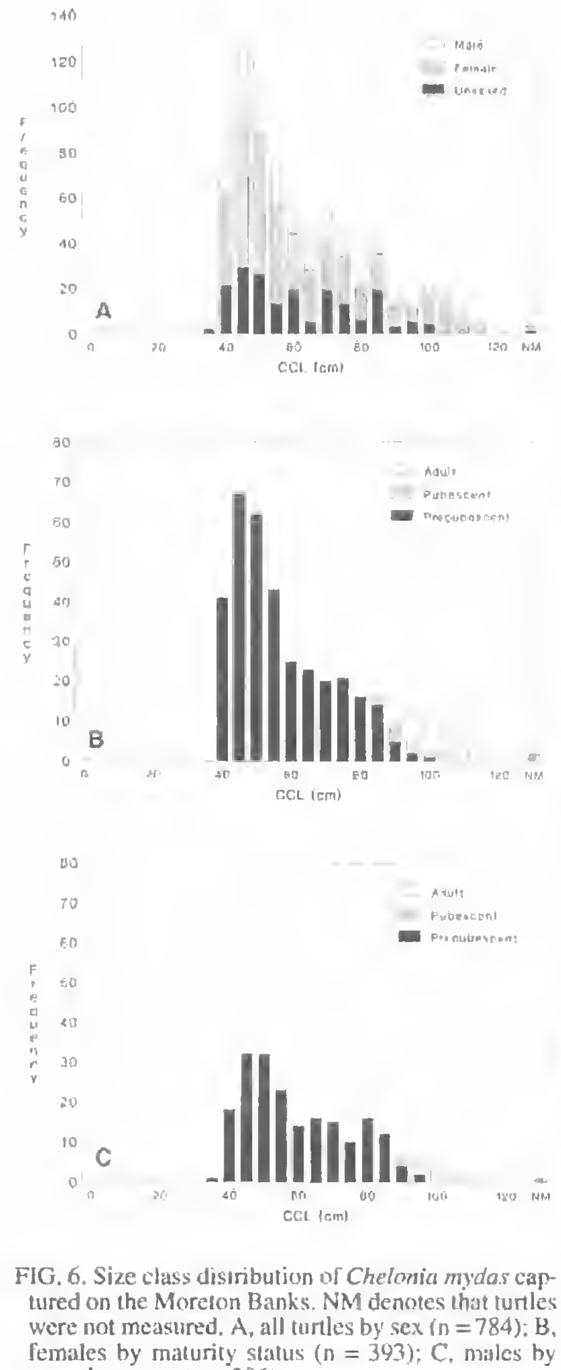

FIG. 6. Size class distribution of *Chelonia mydas* captured on the Moreton Banks. NM denotes that turtles were not measured. A, all turtles by sex (n = 784); B, females by maturity status (n = 393); C, males by maturity status (n = 206).

adult, 2.5% pubescent immature and 86.5% prepubescent immature. The mean size (CCL) of the adult females was 107.9cm (Table 4). This mean adult female size is not significantly different from the mean size of nesting female *C. mydas* from the southern GBR (CCL = 107.0cm, s.d. = 5.318, range = 91-124, n = 1942; $F_{1,1981}$ = 1.07, p 0.5; Limpus et al., 1984). Of the 57 females in the adult size range (CCL ≥ 90cm) that were assessed for maturity, 28% were still immature (8 prepubescent, 8 pubescent). The size (CCL) of the largest prepubescent immature female was 100.5cm while the largest pubescent immature female was 108.1cm, slightly larger than average breeding size for this population. This latter immature turtle was assessed as being several years away from sexual maturity. The mean size (CCL) of pubescent immature females was 96.7cm (Table 4).

Of the 206 males identified in this study, there were 3.9% adult, 1.0% pubescent immature and 95.1% prepubescent immature (Table 3). The mean size (CCL) of the adult males was 102.1cm (Table 4). These adult males were not significantly different to the size of the breeding male *C. mydas* recorded in courtship aggregations in the southern GBR (mean CCL = 100.6cm, s.d. = 4.609, range = 89.5-114.5, n = 361, $F_{1,367}$ = 0.84, p 0.5; Limpus, 1993.). The largest immature male measured (CCL) = 98.8cm. The mean size (CCL) of pubescent immature males was 93.6cm (Table 4).

The results of analysis of covariance, by sex, of the various measurements taken on these turtles are summarised in Table 5. No differences between the sexes, indicated by coincidental regression for males and females, were identified when CCL was compared with each of CCW, SCL, CSCL, SCW, HL or PL and TLC for immature turtles having CCL <80cm. The regressions for this suite of characters were recalculated, pooling the values for both sexes (Table 5; Fig. 7). With each of these pooled regressions, except for CCL:TLC there was little scatter about the relationship as indicated by the high r^2 values. Thus, except for tail length, any one of these measurement methods could be used as a standard measure for this species, and the others could be derived from it. Given the low cost of fibreglass tape measures and the ease with which CCL can be measured in a variety of field conditions, both in and out of water, CCL is recommended as the basic standard length measure for *C. mydas*. *C. mydas* was sexually dimorphic with respect to analysis of covariance comparison of regression analyses of CCL:HW, HL:HW and logCCL:logWT. The results of these analyses by sex are summarised in Table 5. However, the degree of sexual dimorphism is small, as can be seen by inspection of the data (Fig. 7C,D,F), and

TABLE 3. Frequency distribution by size class, sex and maturity for *Chelonia mydas* captured on the Moreton Banks.

Sex	Maturity Status					Total
	Adult	Immature				
		Pubescent	Pre-pubescent(CCL cm)			
			≥90.0	<90.0-≥65.0	<65.0	
Male	8	2	6	72	118	206
Female	43	10	8	94	238	393
Unsexed	11 uncertain status			64	110	185
Total	62	12	14	230	466	784

little confidence can be placed in sexing turtles based on these relationships.

While immature turtle with CCL <80cm were not significantly sexually dimorphic with respect to tail length (TLC), adult turtles were markedly dimorphic with respect to this character (Fig. 7E). However, even with this character there is overlap in measurements with some immature males and small adult females. There were 58 adult-sized, short-tailed turtles that externally resembled "adult female" *C. mydas* that were examined using a laparoscope to determine their sex and maturity. One (2%) was found to be a prepubescent immature male (CCL = 92.0cm, TLC = 7.0cm). Among the 57 females, there were 8 pubescent and 8 prepubescent immatures and 41 adults. Thus if there had been no gonad examination and only the measurement of carapace and tail had been used to determine sex and maturity, the adult female component of the population could have been over estimated by 42%. These data demonstrate that for both female and male *C. mydas*, most do not reach maturity at a minimum breeding size but at a size approaching the average breeding size for the population.

TABLE 4. Curved carapace length (cm) of adult and pubescent *Chelonia mydas* captured on the Moreton Banks.

		mean	SD	n	range
Female	adult	107.9	5.58	41	98.5 - 119.1
	pubescent	96.7	7.54	10	87.7 - 108.1
Male	adult	102.1	2.22	8	98.6 - 105.1
	pubescent	93.6		2	93.2 - 93.9

The 11 turtles scored with "uncertain maturity status" (Table 3) include those turtles with undifferentiated tails that were adult sized CCL>90cm but whose reproductive systems were not examined to assess maturity. These turtles, while they were probably females, have not been assigned a maturity status.

The sex ratio of immature turtles, considered in 5cm CCL size class increments from 40-90cm, was significantly different to 1:1 ($X^2 = 51.02$, 9d.f., $p < 0.001$). Stepwise unweighted logistic regression showed that sex ratio was variable within the population, being significantly correlated with maturity status, size class of the turtle and a cross product interaction of size with maturity status for adult turtles (Table 6). When these data are pooled across all size classes and maturity status classes, it resulted in a sex ratio for *C. mydas* on the Moreton Banks of male : female = 1 : 1.91, i.e. 65.6% of the population was female.

The proportion of adult females that bred in each of four breeding seasons (bred/total number examined) were: 1988-1989 = 1/13; 1989-1990 = 6/15; 1990-1991 = 1/16; 1991-1992 = 2/12. A chi squared test for heterogeneity did not detect significant interseasonal variability in annual breeding rates for these adult females ($X^2 = 7.4$, 3d.f., $p = 0.06$). This result was influenced by the small annual sample sizes. Averaged over these four years, the annual breeding rate = 18% of the adult females that feed in this area. The adult males were not identified to the season in which they bred.

Four immature *C. mydas* were recorded with deformed spines (3 with scoliosis: males, CCL = 70.0, 98.1cm;female, CCL = 50.5cm. 1 with kyphosis:male, CCL = 81.3cm). Fibropapillomas (Fig. 8) were recorded on 62 (7.9%) of the 784 *C. mydas* examined in this study. The frequency distribution by size class of turtles with fibropapillomas is shown in Fig. 9. This disease appears to be externally recognisable most frequently with large immature turtles: average size of turtles with fibropapillomas was CCL = 74.1cm (s.d. = 11.51, n = 62, range = 48.0-102.1). Three other obviously sick turtles that did not swim vigorously and were emaciated and with extremely sunken plastrons (females, CCL = 99.1cm, 41.8cm; male, CCL = 78.4cm) were captured.

The turtle barnacle, *Chelonibia testudinaria*, was the most obvious barnacle on these turtles and was restricted to the more rigid surfaces of the turtles: carapace, plastron and head and oc-

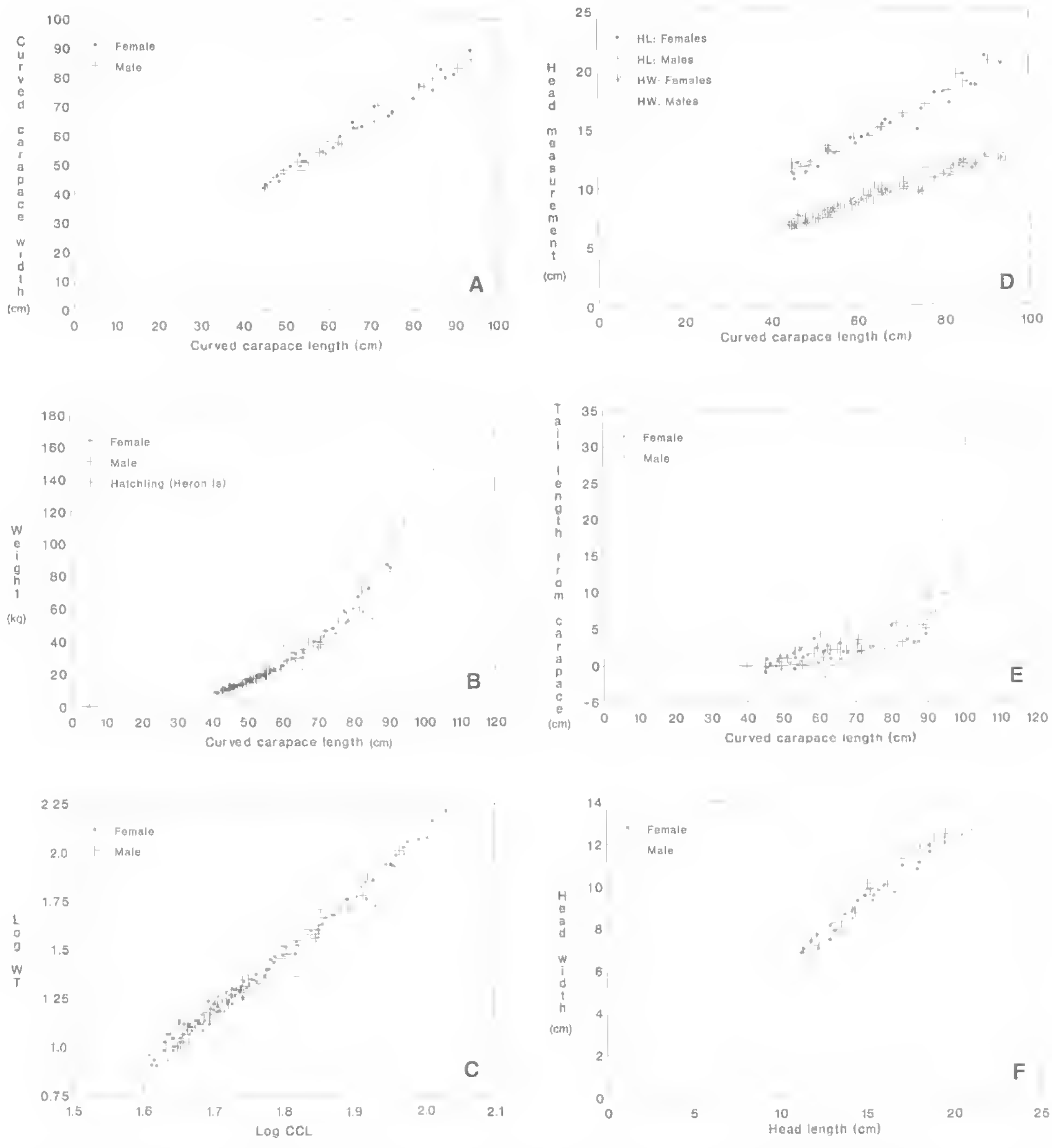

FIG. 7. Scatter plots of morphometric data recorded from *Chelonia mydas* from the Moreton Banks. A, curved carapace length / width (n = 56); B, curved carapace length / weight (n = 198); C, log / log regression of curved carapace length / weight (n = 198); D, curved carapace length / head measurements for the separate sexes (female = 31, male = 25); E, curved carapace length / tail length from the carapace (n = 103); F, head length / head width (female = 31, male = 25).

curred rarely on the flippers. *C. testudinaria* >1cm diameter on the carapace were counted on 814 turtles: this barnacle was recorded on 52.9% of the turtles (mean count of 2.6 barnacles per turtle, s.d. = 5.584, range = 0-93; Fig. 10). There was no obvious correlation between the size of the turtles and the number of *C. testudinaria* >1cm diameter that they carried on the carapace. Two adult female *C. mydas* (CCL = 104.8, 116.6 cm) had large infestations of the burrowing bar-

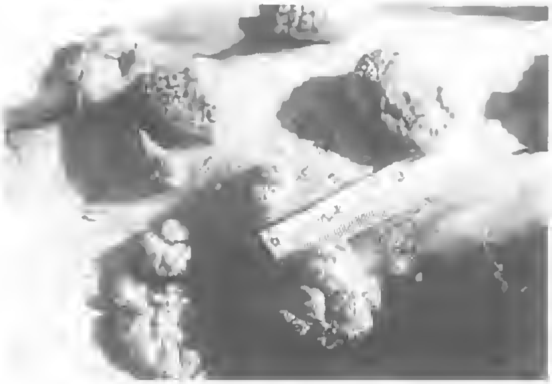

FIG. 8. Fibropapillomas at the base of the front flipper of an immature *Chelonia mydas*. Upper scale in inches, lower scale in centimetres.

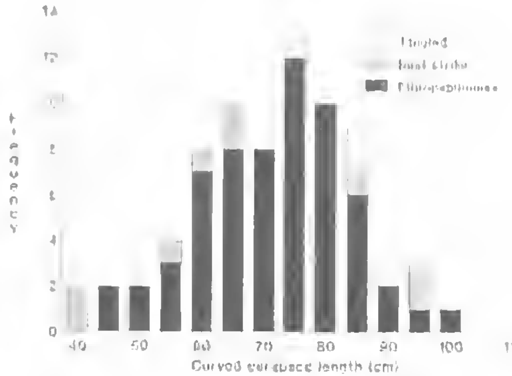

FIG. 9. Frequency distribution by size of sick and injured *Chelonia mydas* from the Moreton Banks

nacle, *Tubicinella cheloniae*, in the carapace. Neither of these turtles appeared to be debilitated by these barnacles. Isolated individuals of this barnacle were found on few other turtles. Other commensal barnacles included *Platylepas decorata* which occurred in appreciable numbers on the skin rather than the rigid surfaces of almost every turtle; the small burrowing barnacle *Stomatolepas transversa* which were found in the plastronal grooves of the larger turtles; *Stephanolepas muricata*, another small burrowing barnacle, occurred in small numbers burrowed through and between scales on the leading edge of the front flippers. Ozobranchid leeches, *Ozobranchus margoi*, and/or their eggs occurred on almost every turtle and were very numerous on turtles with enlarged fibropapillomas. Thirteen turtles displayed evidence of having been impacted by anthropogenic activities (Fig. 9). Four (0.5%) of the turtles had been tangled in rope or fishing line: one (CCL = 89.5cm) had a rope and another (CCL = 94.5cm) had a large length of fishing line tightly tangled around a front flipper (In each case the affected flipper was functional but partly debilitated); two (CCL = 77.2, 85.8cm) were tangled in float lines to crab-pots and would have drowned had they not been released. Nine (1.1%) of the turtles examined had damage to the carapace, in varying stages of healing, that was consistent with the turtle having been struck by a boat or propeller (This value does not include any *C. mydas* that have died following a boat-strike). These turtles with boat-strike injuries (Fig. 9) include almost the entire size range of turtles occurring on the Moreton Banks (Fig. 6A). None of the *C. mydas* examined had unhealed wounds that would have been consistent with their having been attacked recently by sharks or other predators.

Many of the turtles were observed actively feeding and they often had food items still in their mouths as they were lifted on board the catch boat. The common mouth contents, in order of frequency of occurrence, were pieces of seagrass (*Halophila ovalis, Halodule uninervis, Zostera capricorni, Halophila spinulosa*) and algae (*Hypnea cervicornis*). These turtles were also occasionally observed feeding on jellyfish (*Catostylus mosaicus*). A detailed study of the diet of these turtles has been the subject of a separate study (Read, 1991) and will be reported on separately. The turtles foraged into the intertidal areas, moving in with the rising tide and back to permanent water with the falling tide. The turtles had two choices in leaving the intertidal areas with the falling tide; they could move into small gutters within the inner drainage area of these extensive banks or they could swim to the outer edge of the banks. The former was more accessible to turtles that foraged towards the middle of the Moreton Banks. A total of 598 measured *C. mydas* had their location within the Moreton Banks recorded when captured and large and small turtles were found to have different distributions on these banks. Large turtles, CCL $\geq$ 80cm, were rarely encountered on the inner drainage areas (0.5% of captures, n = 192) while they were regularly captured within the outer drainage areas (31.3% of captures, n = 406). There were 241 recaptures on the Moreton Banks of turtles previously tagged on the Moreton Banks during this study. Of these, there were 141 recaptures for which the location within the Moreton Banks was recorded for the consecutive captures of the same turtle. Of these latter recap-

TABLE 5. Analysis of covariance comparison of regression analysis of CCL against other measurements by sex of *Chelonia mydas* resident on the Moreton Banks in eastern Moreton Bay. If there was no significant difference between the sexes when tested for coincidental regression, the measurements for all turtles (male, females and unsexed) were pooled for establishing the final regression in the form : Y = aX + b.

Testing for coincidental regression by sex						Linear regression equation							
X	Y	F	DF	sample size ♀ ♂	P (signifcance)		a	b	n	r^2	F	DF	P
						For pooled sexes							
CCL	CCW	0.73	2,52	(31,25	p>0.25(ns)		0.9101	2.1956	56	0.9760	2194	1,54	p<0.0005
CCL	SCL	0.64	2,52	(31,25)	p>0.25(ns)		0.9251	0.1072	56	0.9935	8224	1,54	p<0.0005
CCL	CSCL	0.03	2,52	(31,25)	p>0.25(ns)		0.9089	1.5616	56	0.9855	3666	1,54	p<0.0005
CCL	SCW	0.14	2,52	(31,25)	p>0.25(ns)		0.7143	6.2796	56	0.9820	2933	1,54	p<0.0005
CCL*	TLC	0.12	2,68	(38,34	p>0.25(ns)		0.0977	-4.2958	72	0.4501	57	1,70	p<0.0005
CCL	HL	2.08	2,52	(31,25)	0.25>p>0.1 (ns)		0.1864	2.9980	56	0.9546	1134	1,54	p<0.0005
CCL	PL	1.30	2,52	(31,25)	p>0.25(ns)		0.7591	3.1303	56	0.9652	1496	1,54	p<0.0005
						For separate sexes							
CCL	HW	6.86	2,52	(31,25)	0.0025>p>0.001	♀	0.1183	1.5804	31	0.9677	868	1,29	p<0.0005
						♂	0.1283	1.2369	25	0.9671	675	1,23	p<0.0005
HL	HW	6.62	2,52	31,25)	0.005>p>0.0025	♀	0.6073	0.1670	31	0.9788	1340	1,29	p<0.0005
						♂	0.7015	-1.1316	25	0.9713	779	1,23	p<0.0005
log CCL	logWT	3.21	2,259	(176,87)	0.05>p>0.025	♀	2.9297	-3.7929	176	0.9860	>9999	1,174	p<0.0005
						♂	3.0274	-3.9725	87	0.9752	3341	1,85	p<0.0005

* CCL/TLC correlaction was tested only for immature turtles with CCL<80cm

tures, 77.3% occurred in the same sector, 18.4% occurred in adjacent sectors within the outer drainage areas, 2.8% involved a shift from the inner drainage to the outer drainage and 1.4% involved a shift from the outer to the inner drainage. There was only one recapture on the Moreton Banks of the 42 turtles tagged elsewhere in Moreton Bay: one of the ten turtles tagged on the Maroom Banks was recaptured on the southern edge of the Moreton Banks, having crossed the Rous Channel. In addition, one of the 23 turtles tagged on the Peel Island seagrass flats was recaptured on the Peel Island seagrass flats. Twenty four immature *C. mydas* were removed from the Moreton Banks and relocated to other areas of Moreton Bay: 9 released at Peel Island with 4 recaptured back at the Moreton Banks; 14 released at Raby Bay with 7 recaptured back at the Moreton Banks; 1 released on the Maroom Banks. The remainder of these relocated turtles have not been recaptured.

While none of the *C. mydas* tagged at the Moreton Banks and released there has been subsequently recaptured at any other feeding area, six of the turtles captured in this study have been found beachwashed elsewhere in the Moreton Bay region. Four apparently have been swept to the east through the Rous Channel (three were found beachwashed and dead on the south eastern end of Moreton Island and one was found beachwashed and dead on the north eastern end of North Stradbroke Island). None of these turtles had external injuries and they were beachwashed along with other similar sized but untagged *C. mydas*. The remaining two were found beachwashed and alive on the western side of Moreton Bay; one displaying disoriented swimming, at Ormiston; the other with four recent propeller cuts to the left shoulder and head, at Victoria Point. This latter turtle was kyphotic and had grown 3.7cm and developed 12 small fibropapillomas in the 1.7yr since it had been first captured.

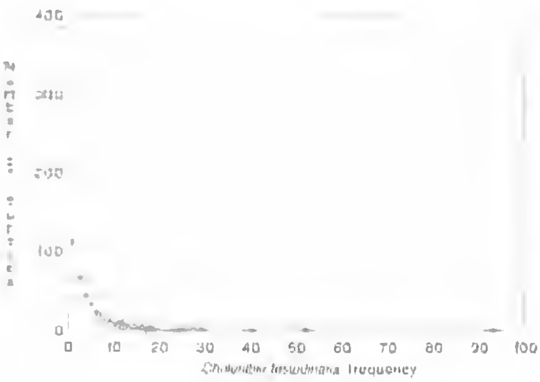

FIG. 10. Frequency distribution of *Chelonibia testudinaria* on *Chelonia mydas* inhabiting the Moreton Banks (n = 814).

In addition, three turtles from the Moreton Banks were killed and used in other studies.

DISCUSSION

The three migrant recaptures of adult females within the present study, when considered in conjunction with other recaptures from elsewhere in Moreton Bay of migrant adult females originating from distant nesting studies (Table 1), demonstrate that the *C. mydas* of Moreton Bay migrate to breed at the rookeries of the Great Barrier Reef. Most of the adult females tagged at nesting beaches and recaptured in Moreton Bay (Table 1) were from the southern GBR rookeries 428-515km distant (94%) while one female had been breeding at Raine Island, 2072km distant in the northern GBR. That the turtles living in Moreton Bay are part of the populations that breed within the GBR is further supported by the recruitment of two small immature turtles to reside on the Moreton Banks that had been originally marked as hatchlings on Heron Island (Table 2). It is within the normal distribution pattern for cheloniid turtles for them to reside at feeding areas that are great distances from their natal rookeries (Limpus et al., 1992).

The capture of T36994 in Moreton Bay during the present study (immature female originally tagged at Heron Island Reef) is the first recapture of a turtle, out of the thousands of *C. mydas* that have been tagged in feeding areas elsewhere in eastern Australia, which has made a major shift in feeding area. However, the results of past mark-recapture studies within the GBR and the Hawaiian Archipelago imply that individual *C. mydas* remain associated with specific feeding sites for extended periods of time (Balazs, 1980; Limpus & Walter, 1980; Limpus et al., 1992). While the isolated instance of movement between feeding sites by T36994 is interesting, it contrasts with the strong site fidelity in evidence in the present study and the local homing to the Moreton Banks of turtles relocated to other parts of Moreton Bay (Similar short range homing has been recorded for *C. mydas* in Bermuda; Ireland, 1979). Until there are additional data to prove otherwise, it is presumed that the majority of individual *C. mydas* remain associated with specific feeding sites.

The oldest museum record of *C. mydas* from Moreton Bay is a skull (Queensland Museum J3841) registered 17 July 1923. Marine turtles were well known to the early aboriginal inhabitants of Moreton Bay who at times hunted them for food (Petrie, 1983). Backhouse (1843), in describing Moreton Bay soon after first European settlement of the area, reported "three species of turtle are met with here, one of which is black and unwholesome". The latter probably was the Leatherback Turtle, *Dermochelys coriacea*. Turtles, especially *C. mydas*, would have been hunted for food for the young colony. Ashton (1941) described a Brisbane scene in about 1880: "In front of one or two of the leading hotels there were enormous turtles chained to the doorpost, with the legend, 'Turtle Soup tonight'". At the turn of the century in Moreton Bay, "... turtles are sufficiently plentiful to attract a little attention. The green turtle, of soup fame, may be found all about the Bay, ..." (Welsby, 1905). A commercial harvest of turtles, presumably *C. mydas*, was occurring in Moreton Bay from at least 1896 (Table 7) and continued until 1950 when *C. mydas* was totally protected in Queensland waters (Limpus, 1980). The Chief Inspector of Fisheries, in eleven of his annual reports to the Queensland Government during the period 1896 - 1924, indicates that there was no shortage of turtles in Moreton Bay (Table 7). However, because of a limited market, the commercial turtle harvest was not great, with the largest recorded annual take probably exceeding 70 turtles in 1900 (Stevens, 1901). During 1924-1929, turtle soup factories operated on North West Island and Heron Island in the southern GBR and at least 8472 female *C. mydas* were taken from the nesting beaches to supply this industry (Anon, 1893-1928; Anon, 1929-1951). Given that *C. mydas* that reside in Moreton Bay are part of the population that nests on these southern GBR rookeries (Table 1; Limpus et al.,

TABLE 6. Results of stepwise unweighted logistic regression of sex ratio by size and maturity of *Chelonia mydas* resident on the Moreton Banks.

			Log-likelihood ratio			
Model	Deviance	d.f.	Source	LR	df	p
S+A+Pu+Pr+SxA+SxPu#	8.28	17				
S+A+Pu+Pr+SxA	8.28	18	SxPr	0	1	p>0.975
S+A+Pu+Pr	14.41	19	SxA	12.3	1	p<0.001*
A+Pu+Pr+SxA	13.53	19	S	10.5	1	0.005>p>0.001*
S+Pu+Pr+SxA	16.96	19	A	17.4	1	p<0.001*
S+A+Pr+SxA	15.17	19	Pu	12.7	1	p<0.001*
S+A+Pu+SxA	8.278	19	Pr	0.004	1	p=0.95
S+A+SxA+C	19.40	19				
A+SxA+C	24.65	20	S	10.5	1	0.005>p>0.001*
S+SxA+C	24.31	20	A	9.8	1	0.005>p>0.001*
S+A+C	25.18	20	SxA	11.56	1	p<0.001*

SxPr dropped from model because it was too highly correllated with other variables.

Dummy variables: A, adult; Pu, pubescent; Pr, prepubescent and cross-products between each of these variables and S. *, source makes a significant contribution to sex ratio; C, constant. S, CCL in 5cm increments.

1992), and given that the southern GBR *C. mydas* population has a mean nesting remigration interval of 6 yr (Limpus et al., in press), the six years of operation of the turtle soup factories on these islands would have reduced the numbers of adult female *C. mydas* in all feeding areas, including Moreton Bay, which supplied females to the southern GBR rookeries.

Following an unsuccessful attempt to produce canned turtle soup on Heron Island, Fogget Jones moved their turtle processing operation to Brisbane in 1927 (W. Golding & Dr. O. Jones, pers. comm.). This Brisbane based turtle soup production continued to utilise female *C. mydas* from the southern GBR rookeries in the years that followed (Anon, 1929-51). It is presumed that this food processing company would have used locally caught turtles from Moreton Bay if they were available but the company's records of turtles and their origins are unavailable. In his 1944 Annual Report the Chief Inspector of Fisheries suggests that only small turtles were captured and brought to the Brisbane market that year, presumably from local sources (Anon, 1929-51). This may reflect a shortage of large turtles at that time. All of the older fishermen working on the Moreton Banks who have been interviewed during the current study indicated that Green Turtles were much less abundant on the Moreton Banks after World War II, i.e. in the late 1940s - 1950s, than they are at the present time.

Although not quantified, there appears to have been some substantial changes in abundance of *C. mydas* in Moreton Bay over the years. The anecdotal information from local fishermen suggests that the *C. mydas* population in Moreton Bay was depleted by the end of World War II and has increased since the introduction of total protection of *C. mydas* for southern Queensland in 1950. If these turtles require in excess of 30 years to reach sexual maturity (Limpus & Walter, 1980), the population resident on the Moreton Banks may represent the result of one generation time of recovery from a depleted state. The small proportion of adults in the Moreton Banks population in the 1990s would be consistent with a population recovering following depletion of adult and large immature turtles resident on the banks in the 1950s. For this interpretation to apply it would require that new turtles recruit to this population at the smaller size ranges and that the turtles do not shift to other distant feeding areas before reaching maturity. In a depleted population of *C. mydas* resident in the Hawaiian Islands, Balazs (1980) described a size structure skewed towards small turtles. The Moreton Banks and Hawaiian populations contrast with the population living on Heron Reef in the southern GBR (Limpus & Reed, 1985a) where

TABLE 7. References to turtles and the turtle fishery of Moreton Bay that are contained in the Annual Reports of the Marine Department (later called the Department of Harbours and Marine) to the Queensland Government, 1893 - 1924.

Year	Comments on the Moreton Bay fisheries
1893-1894	no reference to turtles
1894-95	no reference to turtles
1895-96	report not examined
1896-97	"The turtle fisheries, prosecuted by Mr. Peter Tuska in the Central-Moreton districts, have been found sufficient for the moderate demand of the Brisbane Preserving Works."
1897-98	no reference to turtles
1898-99	"... and turtle are in fair supply when required."
1899-1900	"A good supply of turtle can nearly always be obtained when required."
1900-01	"A very promising trade in turtle has been opened up during the year, several fair consignments having been placed in London and Vancouver by the Brisbane Fish Agency Company, and if regular supplies can be maintained this compay anticipates securing regular orders." The Brisbane Fish Agency Company received "For the year ending 30 June:- .... turtle 70 value £70 ...." (The total catch for Moreton Bay was not documented.)
1901-02	"Turtling which gave promise of developing to a good business last year, has not come up to expectations, the demand being so small, orders for only fifty-three having been received. These orders were soon procured."
1902-03	"Turtle have been plentiful, and the several men following this occupation have been able to supply the demand for turtle."
1903-04	"Turtle-fishing remains an unprofitable occupation, there being next to no demand, a few dozen only meeting all Brisbane requirements. The export trade also appears to be nil, and much to be regretted, a splendid supply being obtainable in our waters could a suitable and steady market be found."
1904-05	"Turtle have also been plentiful in the Bay, but the demand being trifling, only one boat engaged in this trade."
1905-06	"...there is a large field for enterprise in the work of development on the coast of this State, which I fervently hope to see eventually undertaken. Fishing for dugong, turtle, trawling, fish-tinning, fish-curing and salting (especially the curing and salting of eugaree) for export, are all open possibilities."
1906-07	no reference to turtles
1907-08	no reference to turtles
1908-09	no reference to turtles
1909-10	"Turtle fishing has not improved, the demand remaining very limited. A fairly plentiful supply is however, obtainable on our coast if required."
1910-11	"Nothing of any note was done with turtle, there being apparently no demand beyond the call for an odd one or so for the Sydney market."
1911-12	no reference to turtles
1912-13	"The demand for turtle has been very limited, although plenty are obtainable, if required."
1913-14	no reference to turtles
1914-15	no reference to turtles
1915-16	no reference to turtles
1916-17	"Turtles have been plentiful, but the demand very limited."
1917-18	"Turtle fishing has not improved. The demand is still very limited, but a good supply is obtainable on the coast if required."
1918-19	"Turtles were obtainable on the coast in any quantity, but there being no demand only a few for odd requirements were secured."
1919-20	"Turtling has been almost a dead letter. Only a few were caught, there being no demand."
1921-22	no reference to turtles
1922-23	no reference to turtles

the Heron Reef population contained a higher proportion of large immature and adult turtles of both sexes. Given that the resident turtles of Heron Reef have not been subjected to any significant harvest since European colonisation (except for the few females that would have nested locally on Heron and North West Islands during the short period of soup factory operations), the structure of the population on Heron Reef in present times should more closely approximate a natural population. The Moreton Bay study site has a lower proportion of adult *C. mydas* in the population than any other study site examined in eastern Australia (CJL, unpubl. data). Given these considerations, there is the strong possibility that the resident *C. mydas* population in Moreton Bay is presently in a state of recovery from past overharvesting.

Moreton Bay is approximately 400km south of the southern limit for successful annual nesting for *C. mydas* in eastern Australia (Limpus, 1980) and the large numbers of *C. mydas* present in Moreton Bay are not aggregations for courtship or nesting. There is only one confirmed nesting record for the species from Moreton Bay: clutch of 126 eggs laid at Scarborough (27°12'S, 153°07'E), hatchling emerged 21 February 1992 (egg in Queensland Museum, J54440). As is characteristic of *C. mydas* populations studied elsewhere in inshore Australian continental shelf waters (southern Gulf of Carpentaria, Limpus & Reed 1985b; Torres Strait, Parmenter 1980; southern GBR, Limpus & Reed, 1985a) posthatchling turtles (CCL <35cm) are not resident on the Moreton Banks. Posthatchling *C. mydas* are believed to drift past Moreton Bay on the East Australian Current and occasionally occur as beachwashed sick or dead individuals on the ocean beaches outside of Moreton Bay following strong onshore winds (Walker, 1994; Limpus et al., 1994). Once the young turtles recruit to Moreton Bay they remain as residents and all size classes occur from the small immatures (CCL = 39cm) up to large adults of both sexes. These *C. mydas* occur in Moreton Bay all year round.

The present study has not attempted to sample the entire range of habitats within Moreton Bay but has focused on shallow water habitats. Given that larger turtles are more likely to be found at the edges of these shallow banks than in the inner drainage areas, the present study may not describe the size class distribution, sex ratio and possibly other characteristics of *C. mydas* inhabiting the deep water habitats of Moreton Bay. Within the shallow subtidal and intertidal feeding areas of the Moreton Banks these *C. mydas* are primarily herbivorous. The population of the Moreton Banks is strongly biased to females (66%) and to immature size classes (89% of females, 96% of males). Sexual maturity for both sexes does not usually occur at the minimum breeding size but at some larger size. Individual females do not breed annually: averaged over the four breeding seasons, 1988 - 1992, only 18% of the adult females were recorded as breeding in any one year.

The turtles of the Moreton Banks, living adjacent to a city of approximately one million inhabitants, show signs of a range of negative anthropogenic impacts: 0.3% tangled in rope or fishing line, 1% with healing boat/propeller damage, 8% with fibropapillomas (fibropapillomas are presumed to be the result of anthropogenic changes in the marine environment (Balazs & Pooley, 1991). These impacts are absent from the *C. mydas* populations feeding on the coral reefs of the southern GBR (Limpus & Reed, 1985a).

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